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NRL Memorandum Report 2876

Submarine Target Strength Estimates at 1 Khz

[Unclassified Title]

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August 1974

NAVAL RESEARCH LABORATORY
Washington, D.C.

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Submarine Target Strength

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(C) The 1 kilohertz monostatic and bistatic target strength for an attack class nuclear submarine is calculated based upon the extrapolation of a regression model, developed previously, from data on the .233 scale model submarine, KAMLOOPS. These calculations were made to support the active detection performance evaluation of Naval Undersea Center's (NUC) Expendable Sound Source surveillance system concept. The mean 1 khz. Monostatic target strength

(Abstract continues)

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averaged over all aspects is 19.7dB with a 24.9dB and 12.5dB beam and bow/stern aspect target strength, respectively. The 24.9dB beam aspect monostatic target strength agrees exceedingly well with a set of independent measurements made on KAMLOOPS. An expression for the calculation of the bistatic target strength is given.

Submarine Target Strength Estimates at 1 Khz.

by
Carl R. Andriani

(C)The 1 kilohertz monostatic and bistatic target strength for an attack class nuclear submarine is calculated based upon the extrapolation of a regression model, developed previously, from data on the .233 scale model submarine, KAMLOOPS. These calculations were made to support the active detection performance evaluation of Naval Undersea Center's (NUC) Expendable Sound Source surveillance system concept. The mean 1 khz. monostatic target strength averaged over all aspects is 19.7dB with a 24.9dB and 12.5dB beam and bow/stern aspect target strength, respectively. The 24.9dB beam aspect monostatic target strength agrees exceedingly well with a set of independent measurements made on KAMLOOPS. An expression for the calculation of the bistatic target strength is given.

Problem Status: A final memorandum report on a continuing problem

Authorization: NRL Problem Number 81S02-24
Project Number XF52-552-700

Manuscript submitted July 26, 1974.

INTRODUCTION

(C)The Naval Undersea Center (NUC) has developed an Expendable Sound Source (ESS)(1) which operates at 1 khz. The ESS development is part of a system concept for the active detection of submarines. The need for acoustic data to support the detection performance evaluation of ESS, in conjunction with various receiving arrays and source receiver geometries, resulted in a NUC proposal(2) to measure submarine target strengths and reverberation at 1 khz. In support of the proposed NUC measurements, NRL has made estimates of the 1 khz. target strength and reverberant field using models developed at NRL, and based upon the experimental goals and design parameters of NUC. The reverberation calculations are the subject of a separate NRL report(3) and encompass the greater part of the modeling effort. This memorandum report deals with target strength estimates at 1 khz. The objective of the NUC target strength measurements is "to provide submarine target strength for different aspects under controlled conditions" (2) at several bistatic angles.

(U)The proposed experiment, as outlined in reference 2 calls for a far-field measurement at bistatic angles of 0°, 16°, 45°, 90°, 135°, and 157.5°, at aspects of 0° to 90° and 180° to 270° in 15° increments. Based upon the physical symmetry of the target, this suite of aspects is believed to represent the 360° submarine target strength.

ESTIMATE OF 1 KHZ. TARGET STRENGTH

(C)In support of the NUC system evaluation requiring 1 khz. submarine target strengths, NRL has agreed to make target strength computations based on a regression model(4) developed from data taken on the .233 scale submarine model(5) KAMLOOPS (KAMLOOPS is a closely scaled model of the PERMIT and STURGEON class submarines). Those data are characterized by an expression of the form

$$TS=a_o-a_1\beta-a_2\cos 2\Theta, \qquad \text{Eq. 1.}$$

where TS is the target strenght in dB; β (degrees) and Θ (degrees) are the bistatic angle and bistatic aspect, respectively, and are defined in figure 1. The coefficients are functions of acoustic frequency. The unit of a_o is dB, a_1 is dB/degree, and a_2 is dB. The model data was taken over bistatic angles from 0° to 75° at 15° intervals, and bistatic aspects from 0° to 360° at 4° intervals. Evaluation of the coefficients leads to the target strength

formulation

Eq. 2.

$$TS(f)=20+2\cos\left\{[2\frac{f-222}{206}+1]180\right\}-[.26\log f-.60]\beta-5.2\cos 2\theta \pm 5.6,$$

where f is the acoustic frequency (hertz). The term $\pm$ 5.6dB is the residual standard deviation to the regression curve. Equation 2 was developed from data covering 5 discrete frequencies: 244.7, 279.6, 314.6, 349.5 and 384.5 hz. These frequencies correspond to a full scale target equivalent of the KAMLOOPS model, as does eq. 2. The coefficient a_2 is an average over all f.

(C) In developing an expression for target strength at 1 khz. from eq. 2, the following assumptions (with some discussion) are made:

1) Since the second term in equation 2 is cyclical in frequency, an extrapolation of this term to 1 khz. is not unreasonable in that target strength estimates based on physical optics(6) also predicts an oscillatory variation. Thus, the first 2 terms are assumed valid at 1 khz. with the result

$$a_o=20+2\cos\left\{[2\frac{f-222}{206}+1]\right\}180 = 19.7\text{dB}.$$

2) The coefficient of the β term increases monotonically with f and extrapolation to 1 khz. (a_1=.18dB/degree) leads to dubious target strength results. It is assumed instead, that the best estimate for a_1 be determined by averaging the a_1 from the KAMLOOPS test data(4) over all frequencies sampled. The average a_1 is .048 dB/degree. The reasoning leading to this assumption follows. The dependence of a_1 on frequency may be seen by considering the submarine to be made up of several scattering centers. The scattering centers then (upon insonification) give rise to a complicated frequency dependent beam pattern. Thus, as the bistatic angle increases, the particular target strength observed will depend on the angle from which it is viewed for a given frequency. With reference to fig. 2, the increase in the value of a_1 (which is the slope of the target strength dependence on bistatic angle) with frequency suggests what in the simple case of a line array would be the narrowing of the main lobe width (increasing slope of main lobe) with increasing frequency. Thus, looking from some bistatic angle it would appear that the field

intensity (hence the target strength) decreased with increasing bistatic angle at a given frequency; the decrease becoming greater with increasing frequency. Since the beam pattern for a submarine is more complicated than the example just given, one should not expect the simple monotonic form for a_1 given in eq. 2 to extend to 1 khz. Instead, a form which exhibits an oscillatory, but not periodic, behaviour due to the complicated frequency dependent main and side lobe structure should be expected. Since the author believes that the excursion of the oscillation is not large compared to the range of a_1 observed in the KAMLOOPS data, the mean value of the a_1 is thought to be a best estimate for a mean a_1 in the frequency region about 1 khz.

3) The coefficient a_2 = 5.2 dB will be retained.

4) Since the KAMLOOPS data showed the residual variance to the regression curve to be independent of frequency and bistatic angle, the standard deviation of $\pm$5.6dB will be retained at 1 khz.

5) A near-field correction calculation was performed in reference 6 for KAMLOOPS at a monostatic range of 260 feet. At 1 khz. (full scale) the near-field correction was negligible, therefore, a correction to far-field is not considered.

(C) Based on the above assumptions and discussion the expression for the 1 khz. average target strength for a full scale submarine similiar in hull design to the KAMLOOPS is

$$TS=19.7-.048\beta-5.2\cos 2\Theta\pm 5.6\text{dB} \qquad \text{Eq. 3.}$$

(C) Equation 3 has been plotted in figure 3 for the monostatic case (β=o) with the mean target strength value ($\overline{TS}$) over all aspects given in the figure. The mean is a_o=19.7db. To obtain target strength at other bistatic angles, the mean of the monostatic value is adjusted by .048β while maintaining the shape in fig. 3 for the aspect dependence. Since the regression model is based on data which does not exceed 75° in bistatic angle, it is not known whether or not β=90° is at a focus of symmetry. Symmetry is assumed here so that β=22.5° and 45° yield estimates for the proposed NUC measurements at 157.5 and 135°, respectively.

COMPARISON WITH DATA

(C)There is little reported data available at 1 khz. on nuclear attack submarines, to the author's knowledge, with which to test equation 3. A value of 24.8dB is reported in reference 6 for the 1 khz. monostatic beam aspect target strength of KAMLOOPS (the measurements were made by NUC). For β=0 and Θ=90°, eq. 3 yields 24.9dB which agrees exceedingly well with the measured value.

(C)There are some 1 khz. 10 ms pulse data(7) available on POLLACK (SSN 603), an attack submarine of the PERMIT class and similar in design to KAMLOOPS. The form in which this data is presented, and lack of the measurement and signal processing details make comparison of the data with eq. 3 difficult. However, when these data are averaged over aspect angles 75° to 105° (beam aspect) and over all aspects, target strength values of 24dB and 14dB, respectively, are obtained for the 10 ms pulse. The KAMLOOPS data used a 30 ms pulse.

(C)The intent of the above extrapolation of eq. 2 to 1 khz. (eq. 3) is to provide an expression for bistatic target strength of attack class submarines suitable for system evaluation estimates in the absence of data at this frequency. Although eq. 2 is believed valid in the frequency region for which its synthesis was intended, and eq. 3 has some success in predicting the NUC measurement, the extrapolation to 1 khz. should be viewed with some caution until suitable measurements are made.

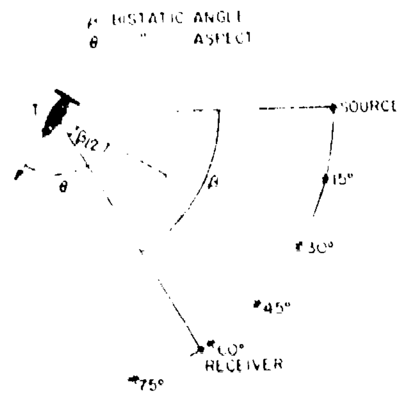

Fig. 1 (U) Bistatic geometry (U)

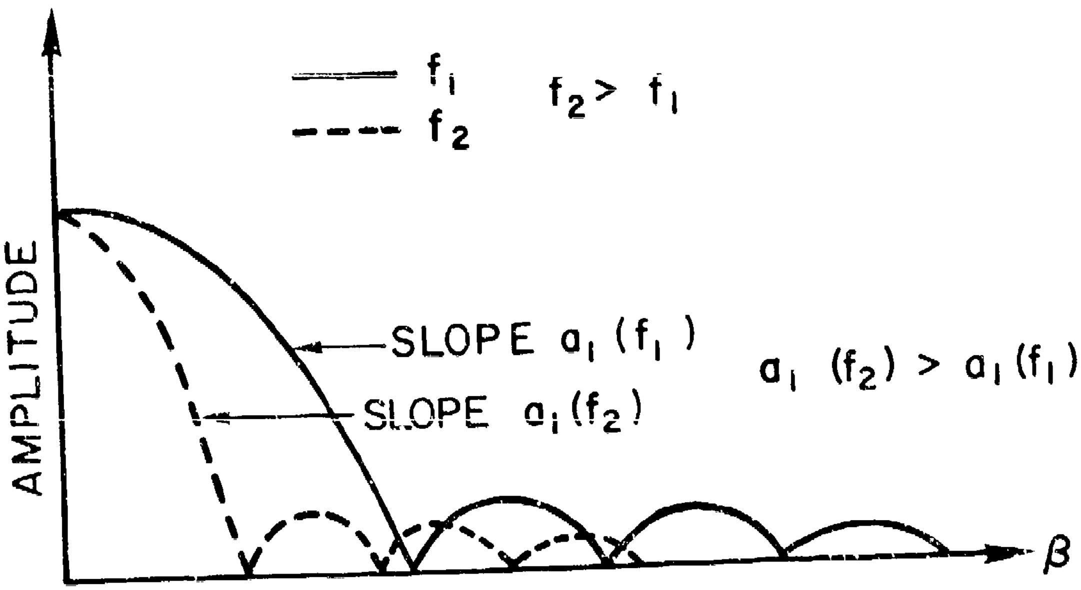

Fig. 2 (U) Beam patterns of a line array (U)

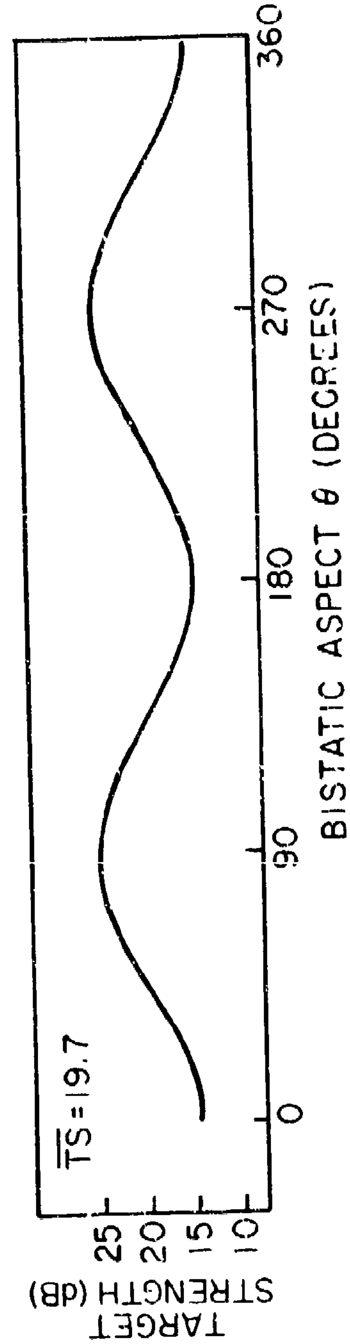

Fig. 3 (C) Plot of eq. 3 for β=0 (monostatic) (U)

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UNITED STATES GOVERNMENT

Memorandum

7100-037

DATE: 26 February 2004

REPLY TO ATTN OF: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF (A) FOR DECLASSIFICATION

TO: Code 1221.1

REF: (a) "Submarine Target Strength" (U), Carl R. Andriani, Acoustics Division, NRL Memo Report 2876, August 1974 (C)

1. Reference (a) describes an estimate of the 1 Khz monostatic and bistatic target strength of an attack class submarine.

2. The technology and equipment of reference (a) have long been superseded. The current value of these papers is historical

3. Based on the above, it is recommended that reference (a) be declassified and released with no restrictions

Burton G. Hurdle

BURTON G. HURDLE
NRL Code 7103

CONCUR:

Edward R. Franchi 3/1/2004

E.R. Franchi Date
Superintendent, Acoustics Division

CONCUR:

Tina Smallwood 3/3/04

Tina Smallwood Date
NRL Code 1221.1